



COSMIC RAY INDUCED HIGH ENERGY EXTENSIVE AIR SHOWERS: EXPLORING EXOTICS IN NOvA



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[SIST FINAL PRESENTATION, AUGUST 4TH, 2014]





OUTLINE

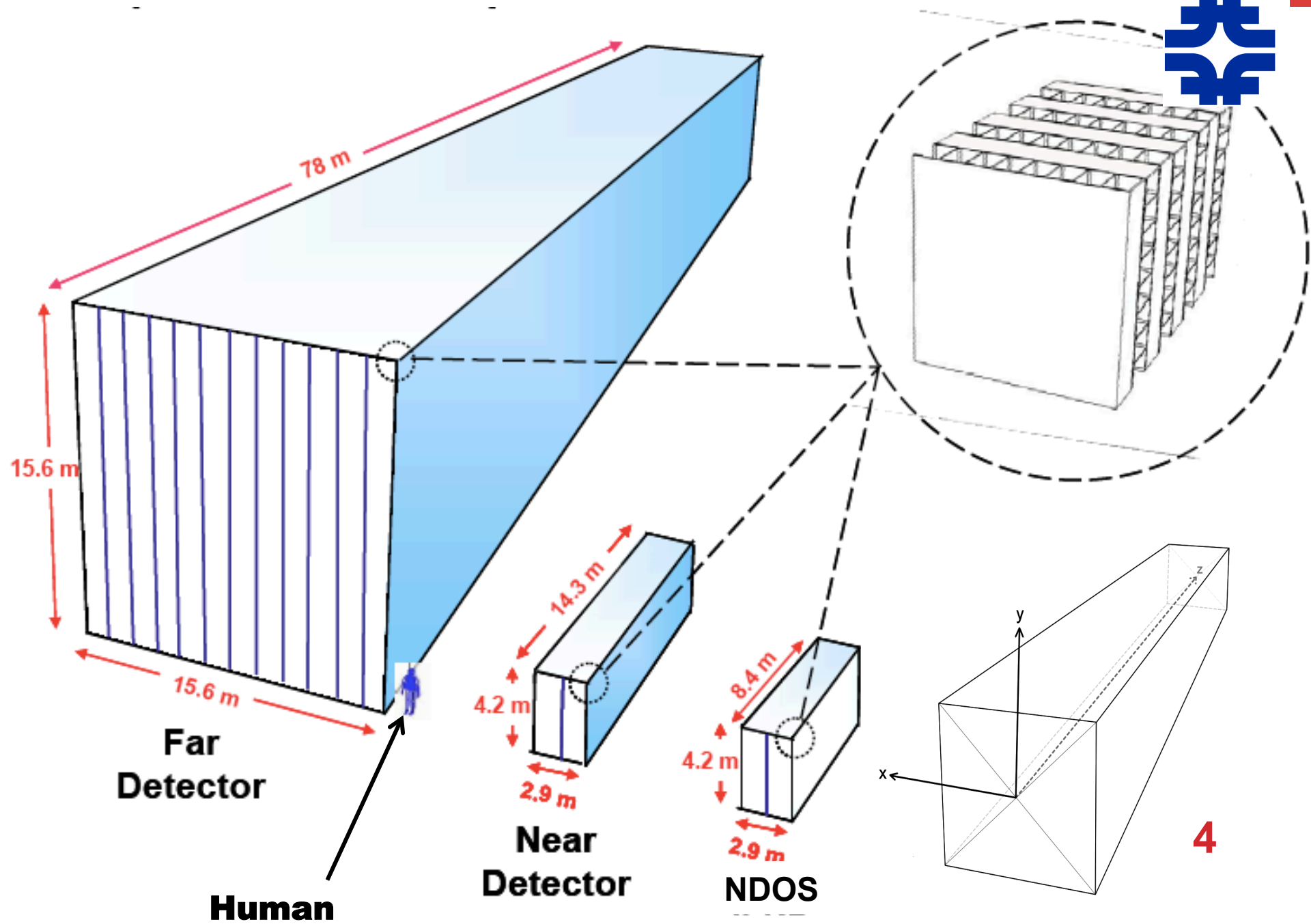
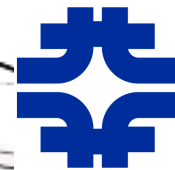
- **Introduction: NOvA Detector Setup, Motivation**
- **Method: Identification and Analysis**
- **Reconstruction/Tracking:**
 - HoughTransform
 - KalmanTrackMerge
- **Future Prospects and Conclusions**



INTRODUCTION – DETECTOR SETUP

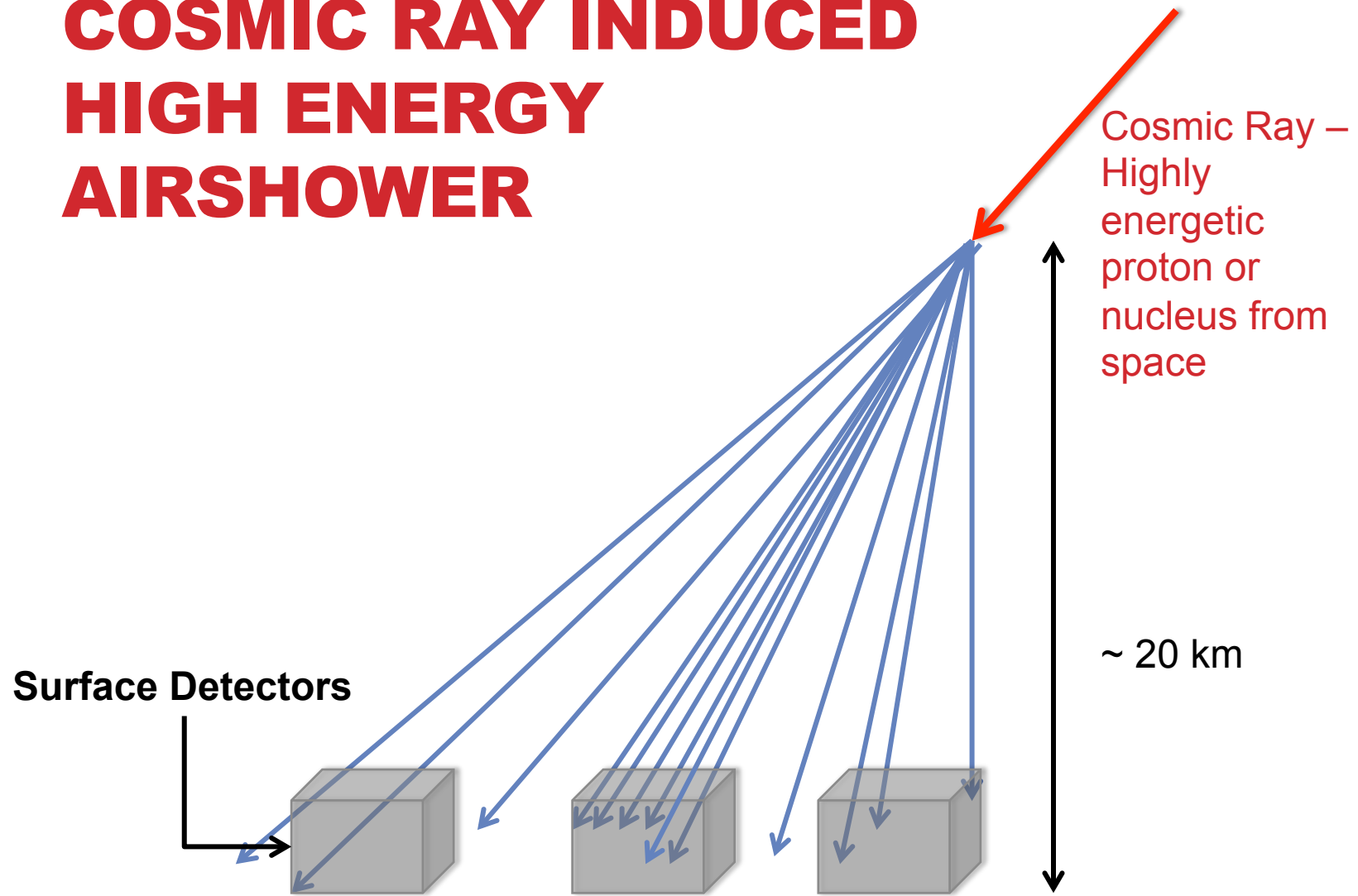


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COSMIC RAY INDUCED HIGH ENERGY AIRSHOWER



Ground/Surface



INTRODUCTION - MOTIVATION

Want to study highly energetic cosmic ray induced air showers

Majority of particles produced in first interactions are pions and kaons which produce large number of muons

- **Easily detectable at sea level**
- **Most of the electrons are absorbed/scattered/canceled out in the overburden above the detector**

Best chance to study air showers in NOvA detectors is through muons

NOvA detectors potentially provide a unique opportunity to study their multiplicity and directionality

How?



STEP 1:

IDENTIFICATION

Events recorded from detector based on high energy triggers.

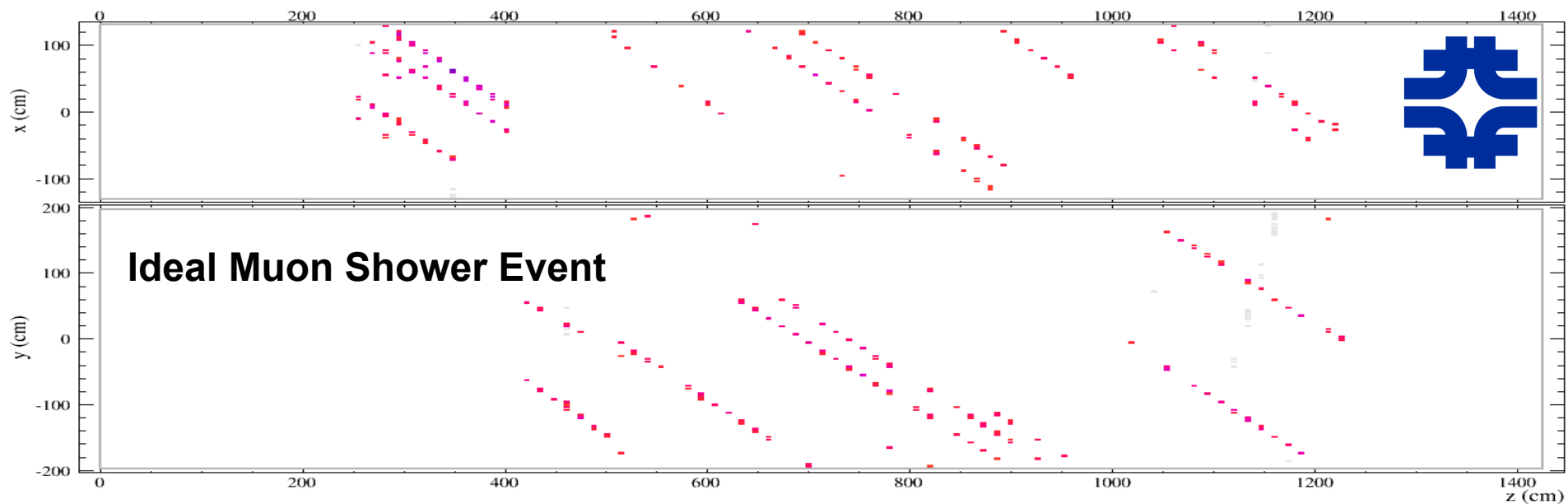
- **NDOS: $> 40,000$ ADC (Analog-Digital (Converter) Counts)**
- **Far Detector: $> 275,000$ ADC**

Cuts on the data allow further filtering and easier identification

Major distinguishing parameters in raw data (that I know of):

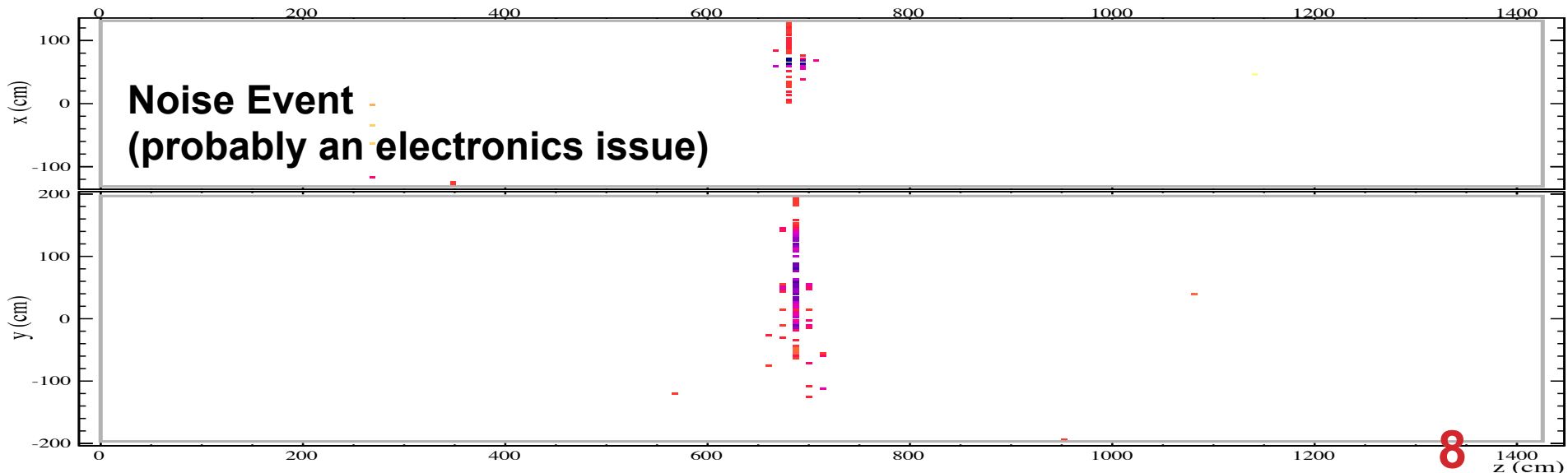
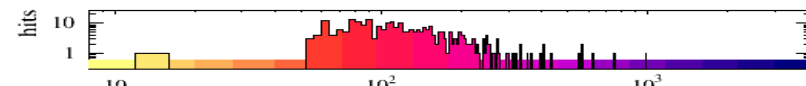
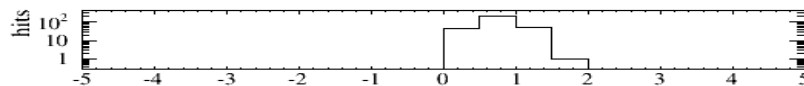
- **Total ADC per slice – sum of ADC counts from each cell in a slice**
- **Average ADC per Cell per Slice (Total ADC/NCells/Slice)**
- **Z extent of the slices/tracks**

Noisy and uninteresting events (and slices) can be filtered out by applying cuts to above parameters



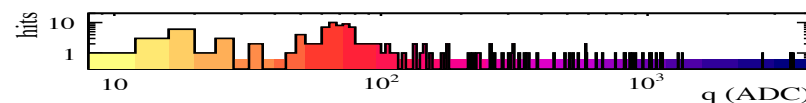
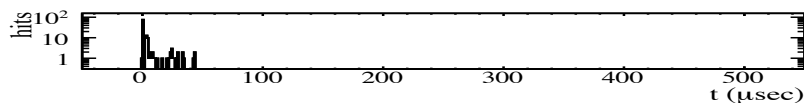
NOvA - FNAL E929

Run: 16333 / 0
Event: 14398 / DDenergy
UTC Fri May 9, 2014
22:24:30.470000500



NOvA - FNAL E929

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Event: 240 / DDenergy
UTC Fri May 9, 2014
22:25:19.315901056



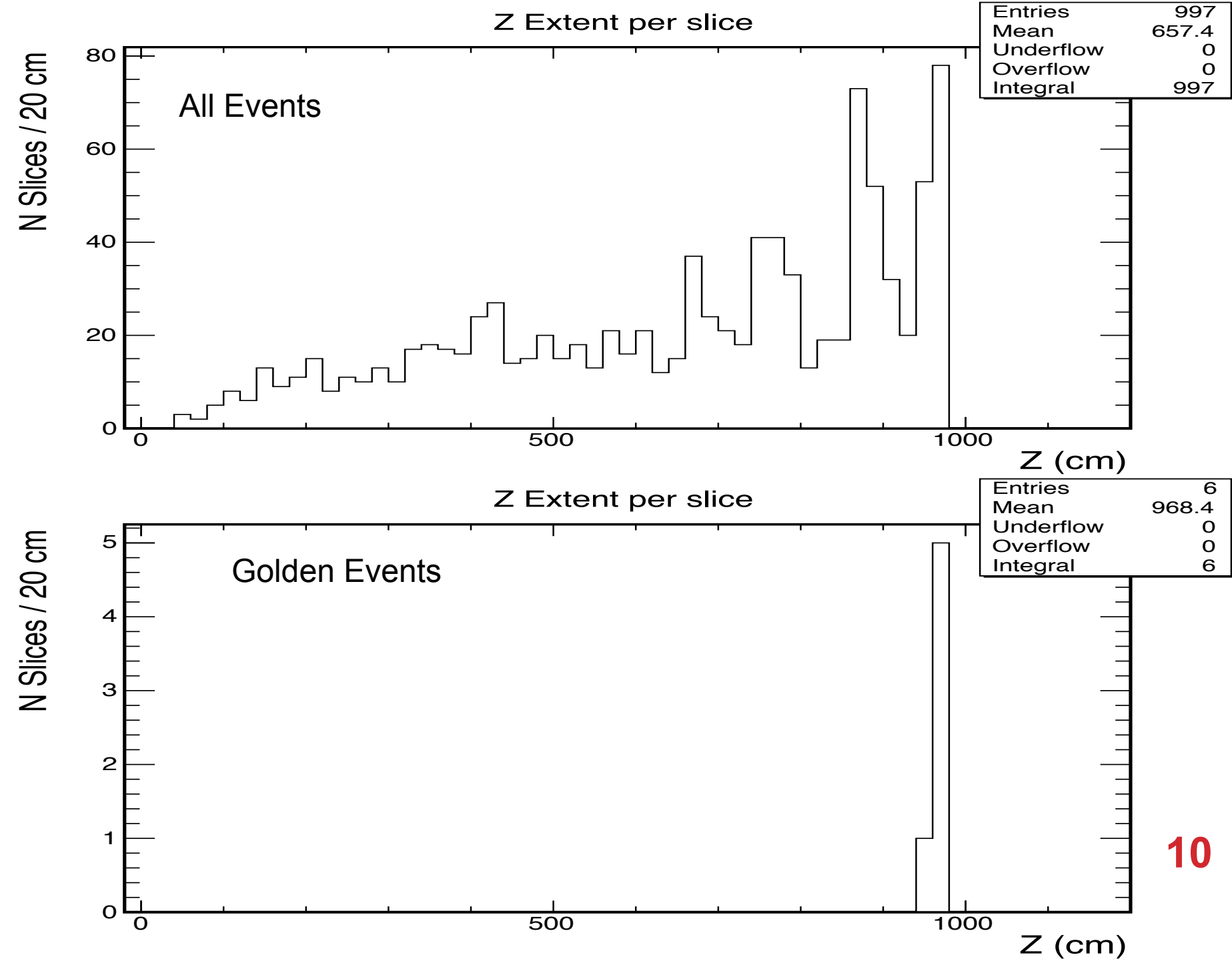


IDENTIFICATION: NDOS

Applied cuts to Total ADC, Average ADC, and Z Extent of the slices to filter out noisy and uninteresting slices

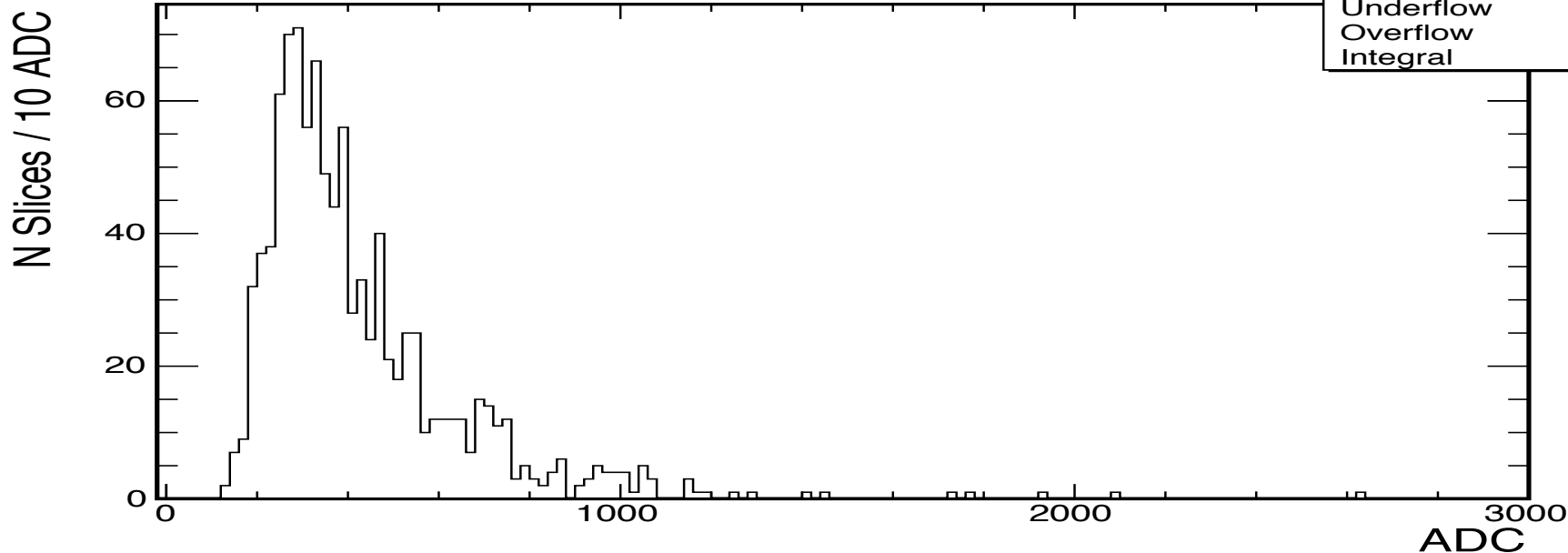
Ideal event candidates (Golden Events) seem to have

- (at least) one slice $> 40,000$ ADC [dependent on multiplicity of tracks]
- Average ADC in range 140-170 (in NDOS)
- Span most of the detector (large Z extent in both NDOS and Far Detector)



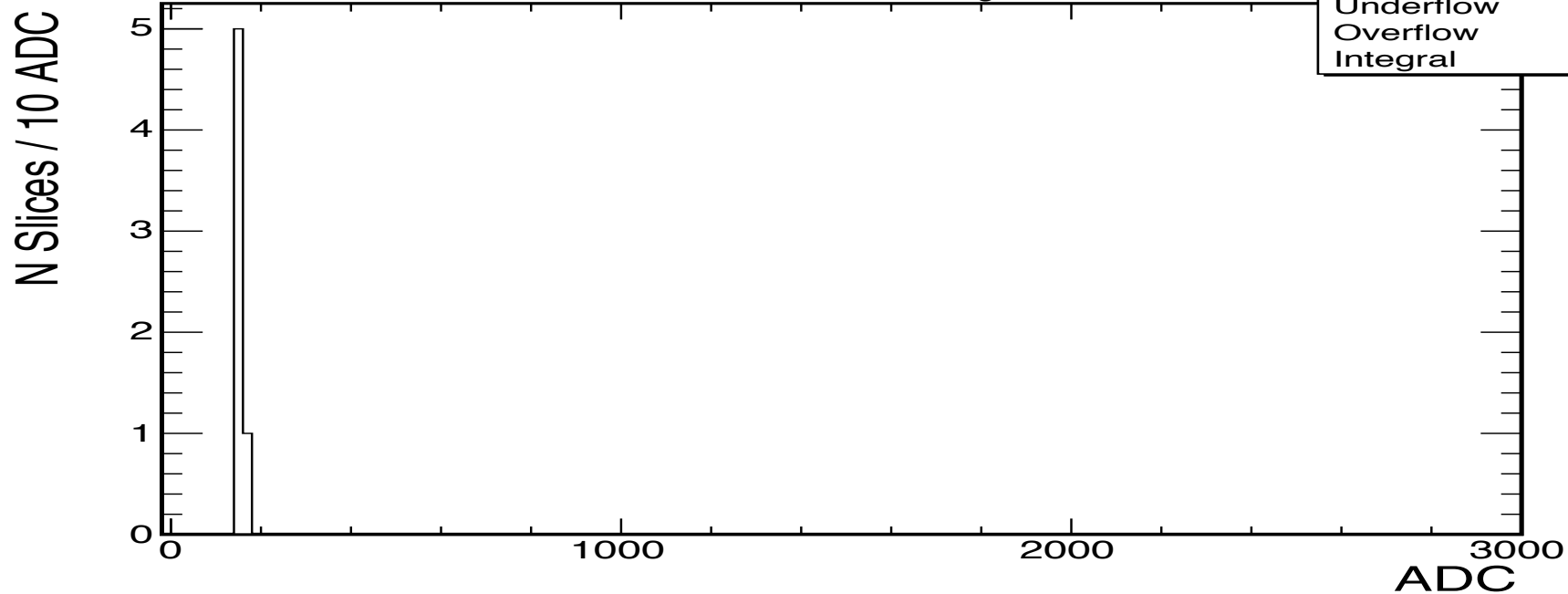
All Events – Average ADC

Entries	997
Mean	426.2
Underflow	0
Overflow	0
Integral	997

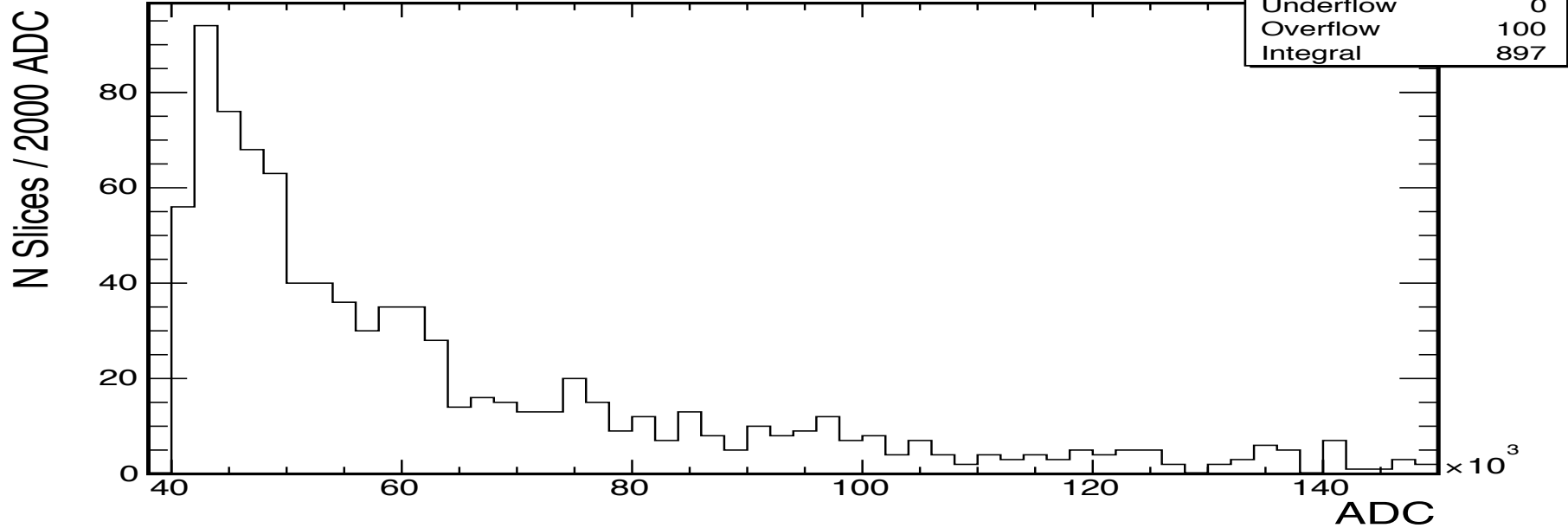


Golden Events – Average ADC

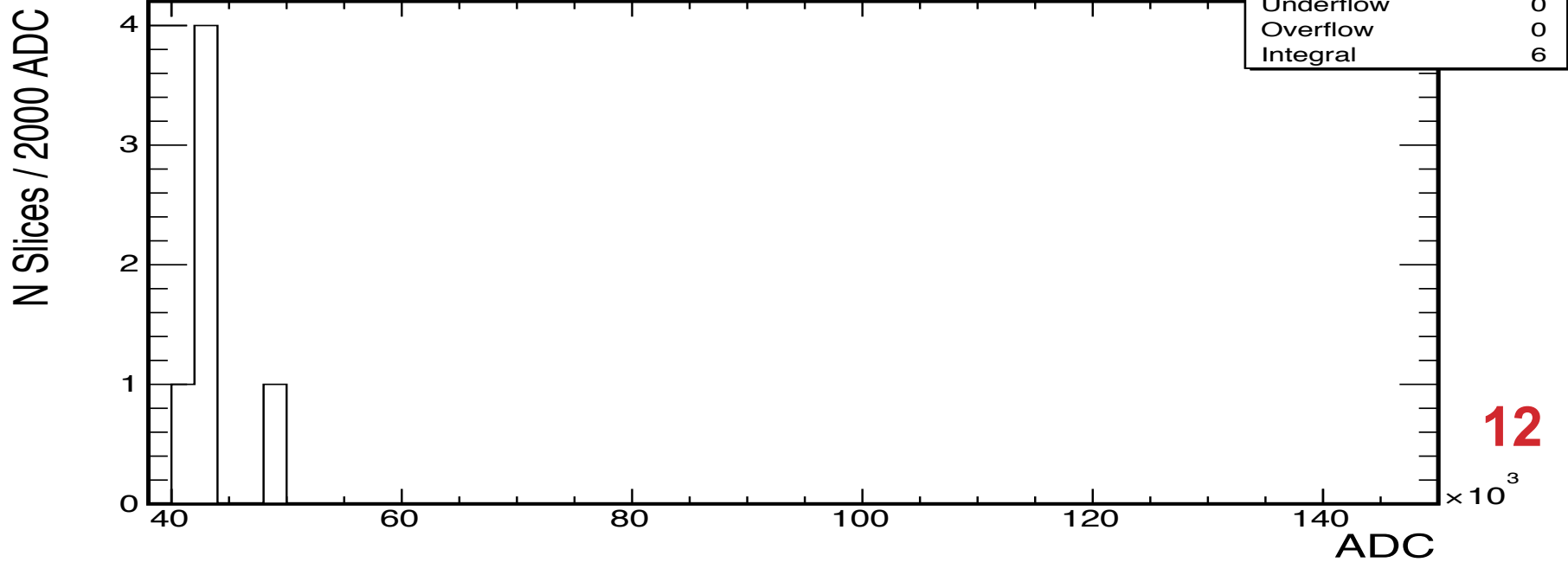
Entries	6
Mean	154.4
Underflow	0
Overflow	0
Integral	6



All Events Total_ADC per slice



Golden Events





STEP 2:

STUDY WHAT THEY LOOK LIKE

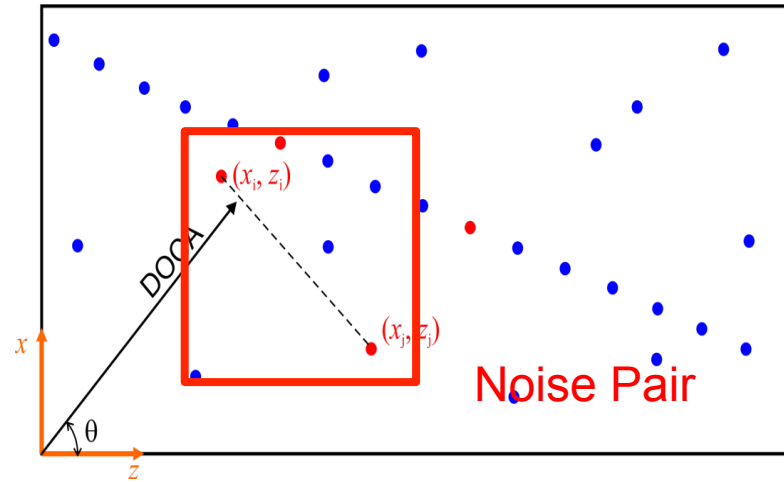
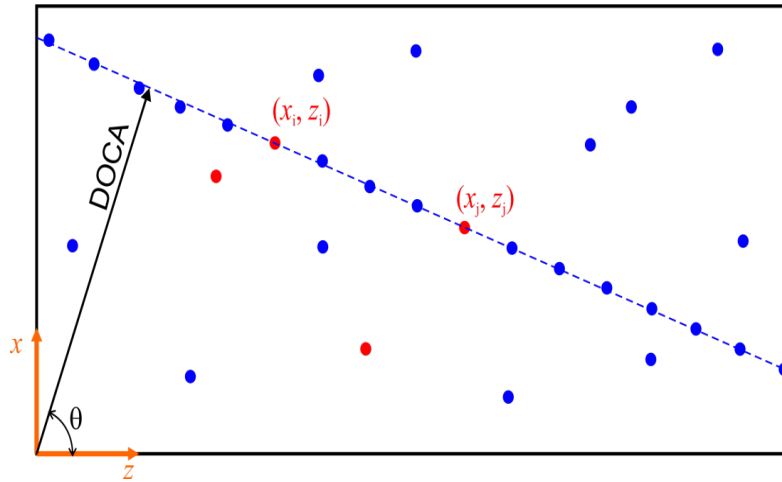
Want to study multiplicity (number of particles) and directionality (angle of track)

Need to reconstruct tracks to find out where they come from in the atmosphere

What is the best approach to extract this information from the data?

- **Tracking:**
 - HoughTransforms – parameterized space, not dependant on start and end points, peaks represent tracks in an event
 - KalmanTrack(Merge) – simply draws lines, based on start and end points of a track

HOUGHTRANSFORM

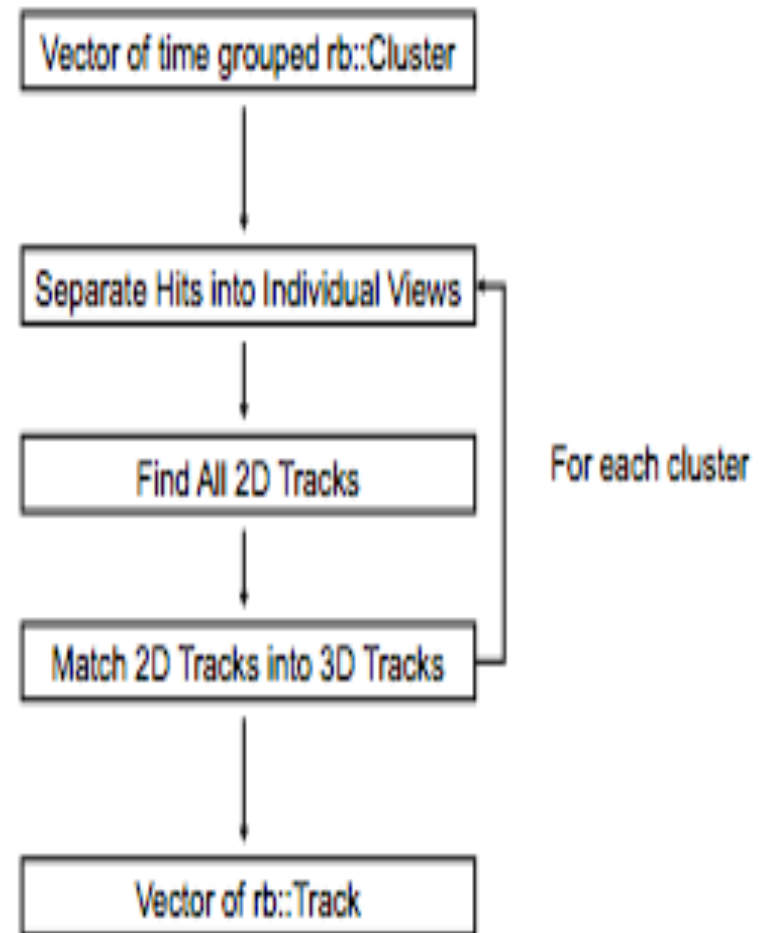


DOCA : Distance of Closest Approach
$$\text{DOCA} = z \cos \theta + x \sin \theta$$

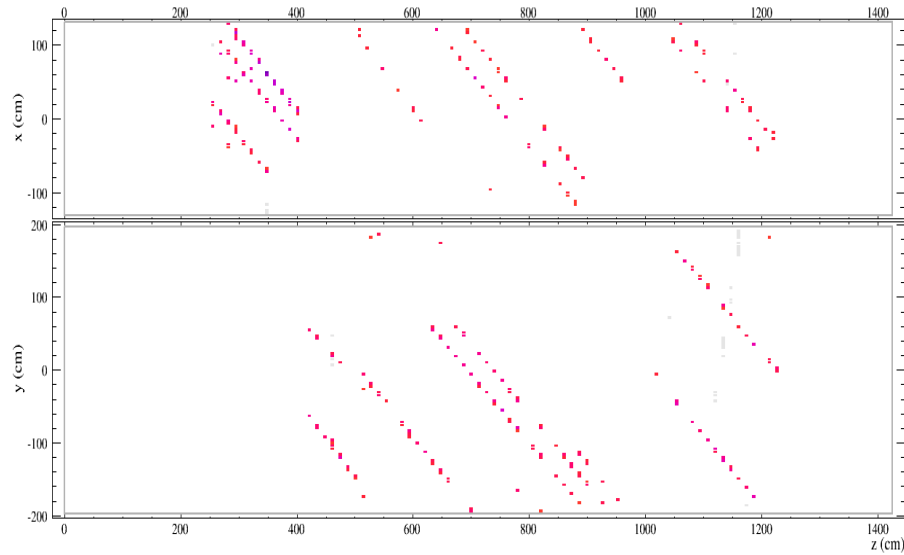


KALMAN TRACK

- Basically only draws lines based start and end points
- Easy to configure parameters
- Does a good job of matching
- Takes a very long time for slices with large number of hits
 - Far Detector:
 - MaxHitCut = 20000!
 - > 30 minutes
 - NDOS:
 - MaxHitCut = 1000
 - < 10 minutes

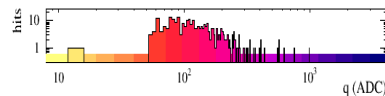
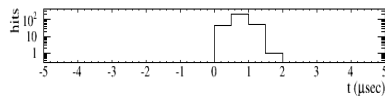


Without Reconstruction



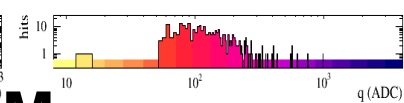
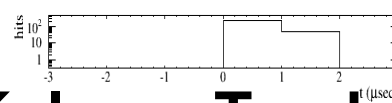
NOvA - FNAL E929

Run: 16333 / 0
Event: 14398 / DDenergy
UTC Fri May 9, 2014
22:34:30.47033568

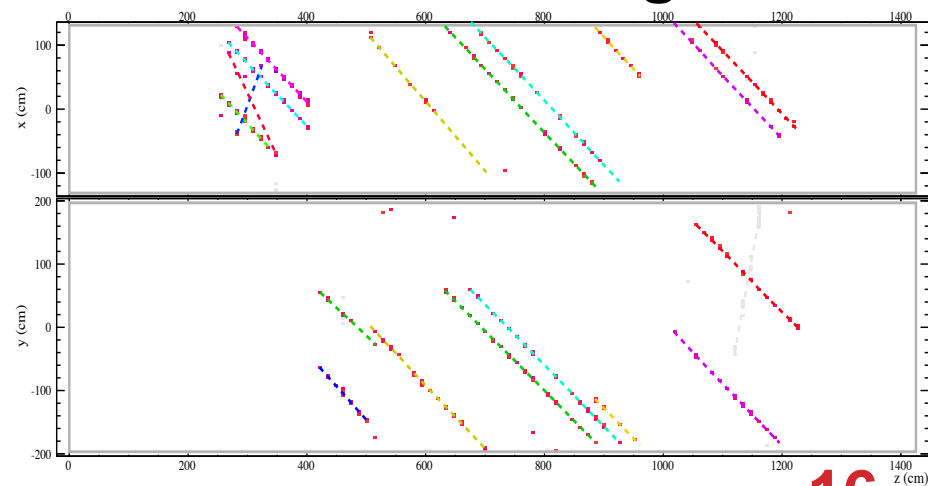


NOvA - FNAL E929

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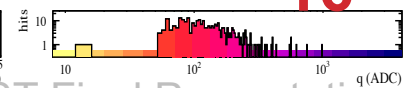
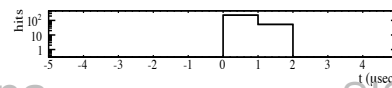


Kalman Track Merge



NOvA - FNAL E929

Run: 16333 / 0
Event: 14398 / DDenergy
UTC Fri May 9, 2014
22:34:30.47033568



NDOS Golden Event

Aug. 4th, 2014

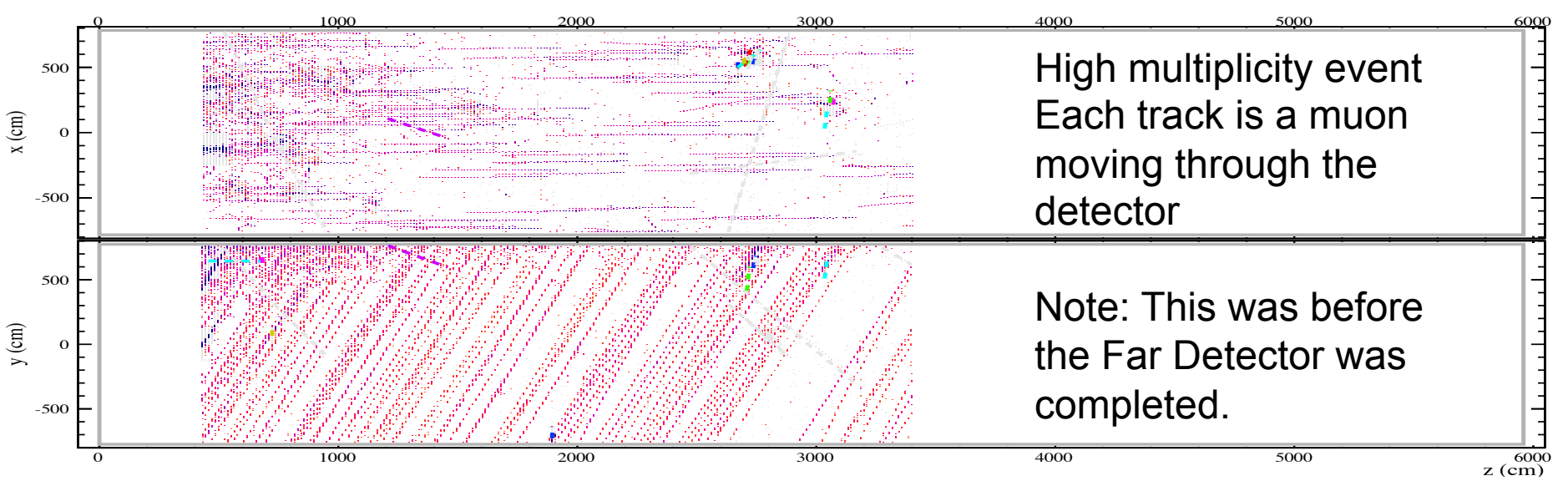
Mehreen Sultana

SIST Final Presentation



FAR DETECTOR: RECONSTRUCTION PROBLEMS

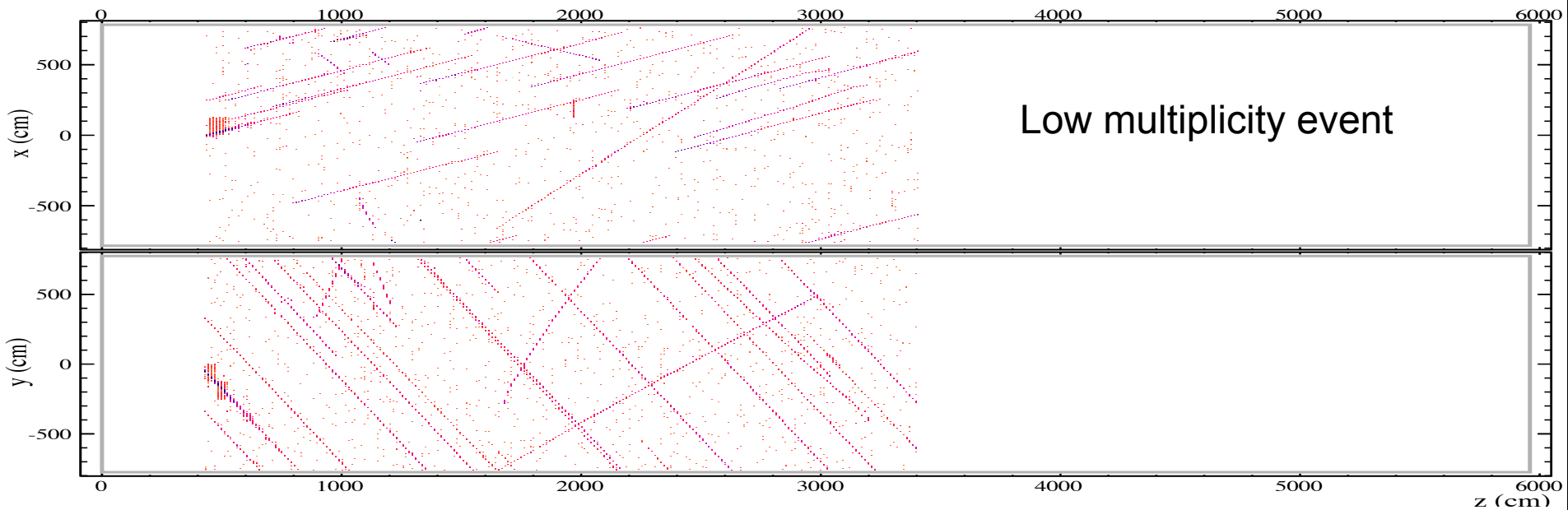
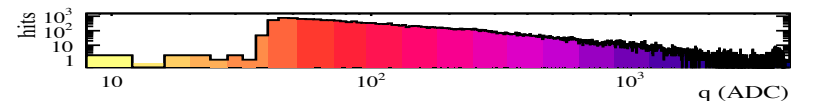
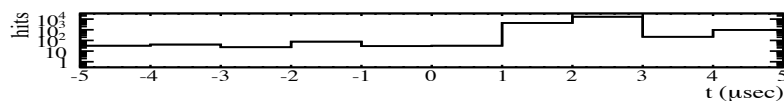
- **Module related:**
 - Large number of muon tracks recorded in a single slice
 - Makes tracking difficult and time consuming because of multiplicity of cell activity
- **Vertical/Steep Tracks:**
 - Few hits in one view make it difficult to reconstruct/match tracks
 - Horizontal tracks appear “broken” because of steepness of the track
- **Low Multiplicity events were used for actual analysis due to time constraints and unreasonable computational time with the available algorithms**



NOvA - FNAL E929

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Event: 981 / DDenergy

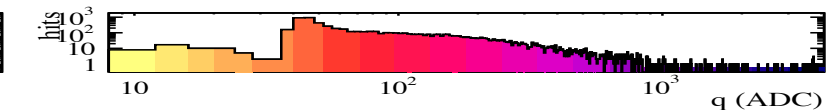
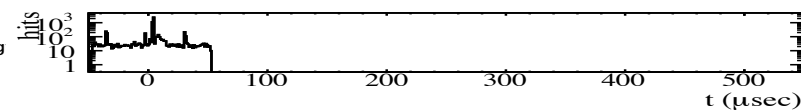
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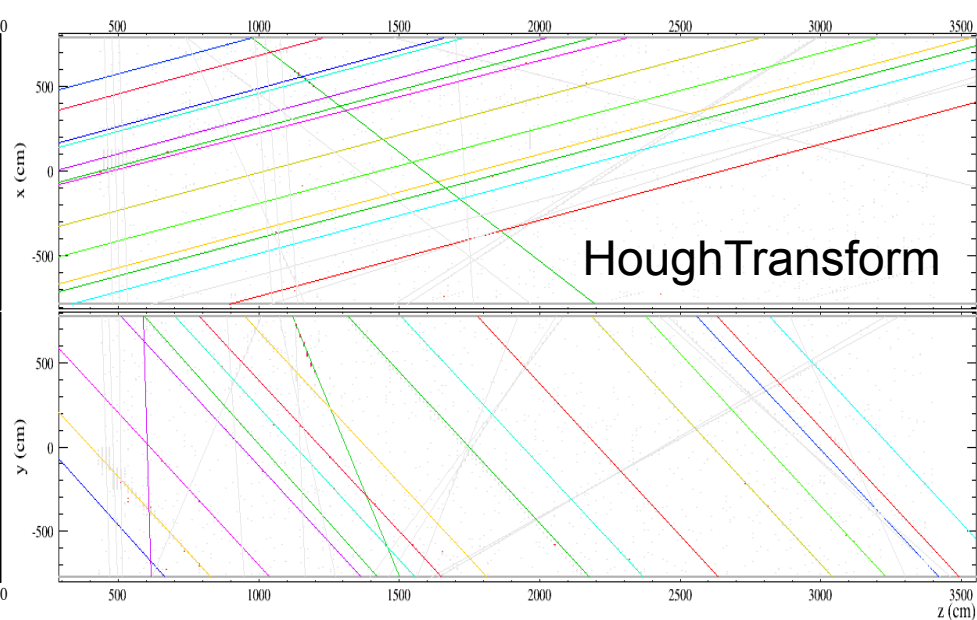
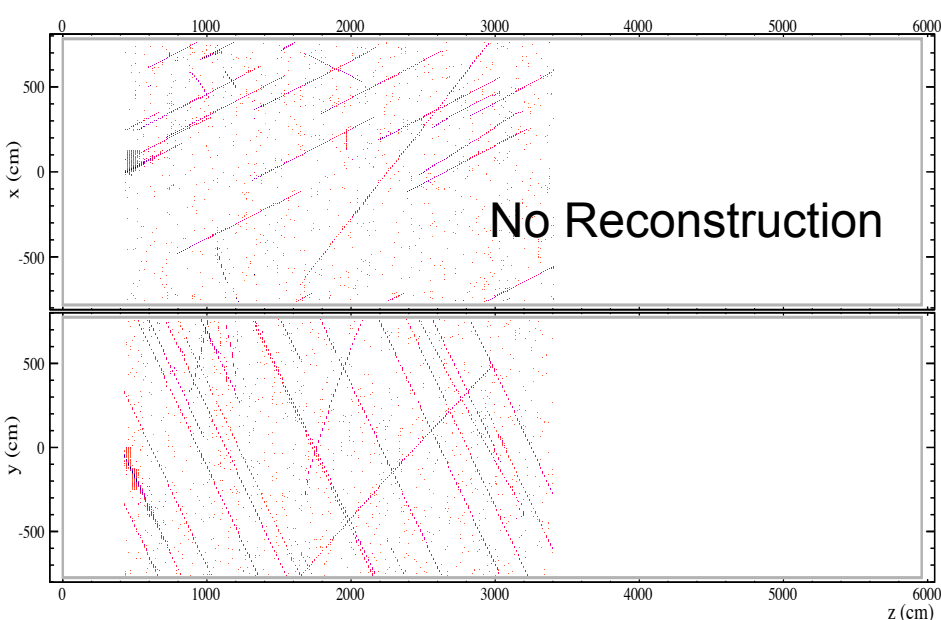


NOvA - FNAL E929

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Event: 1727 / DDenergy

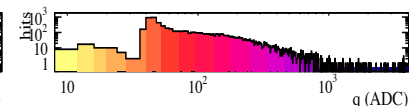
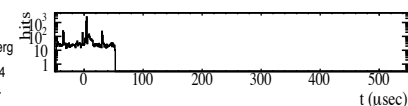
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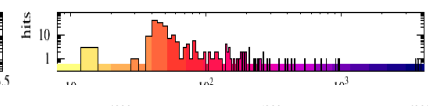
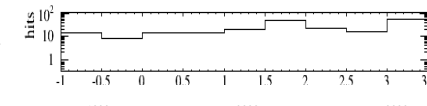
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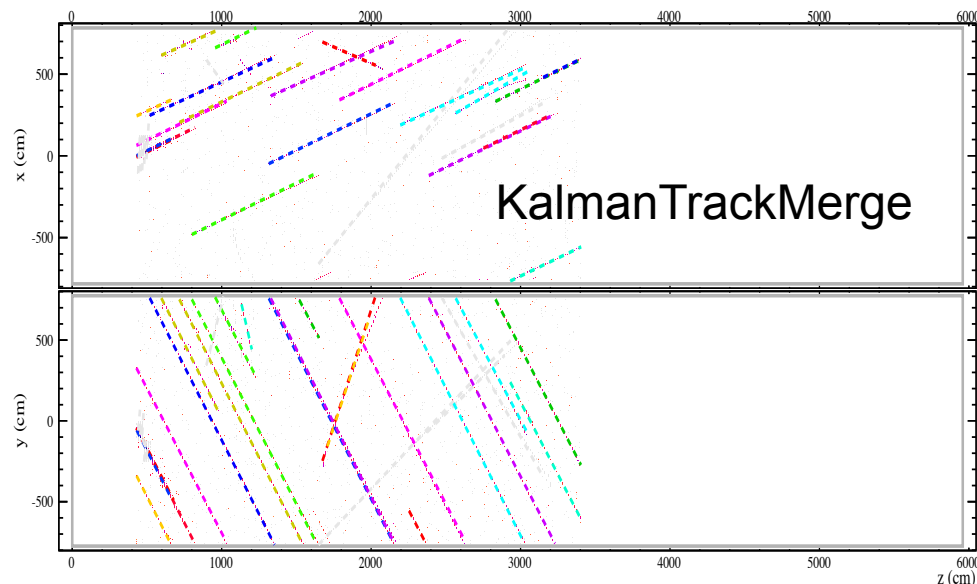


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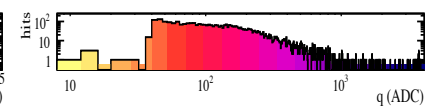
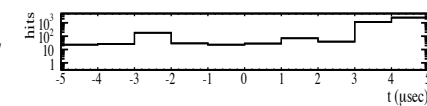


Far Detector Golden Event



NOvA - FNAL E929

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Event: 1727 / DDenergy
UTC Fri Apr 25, 2014
03:12:22.582797504

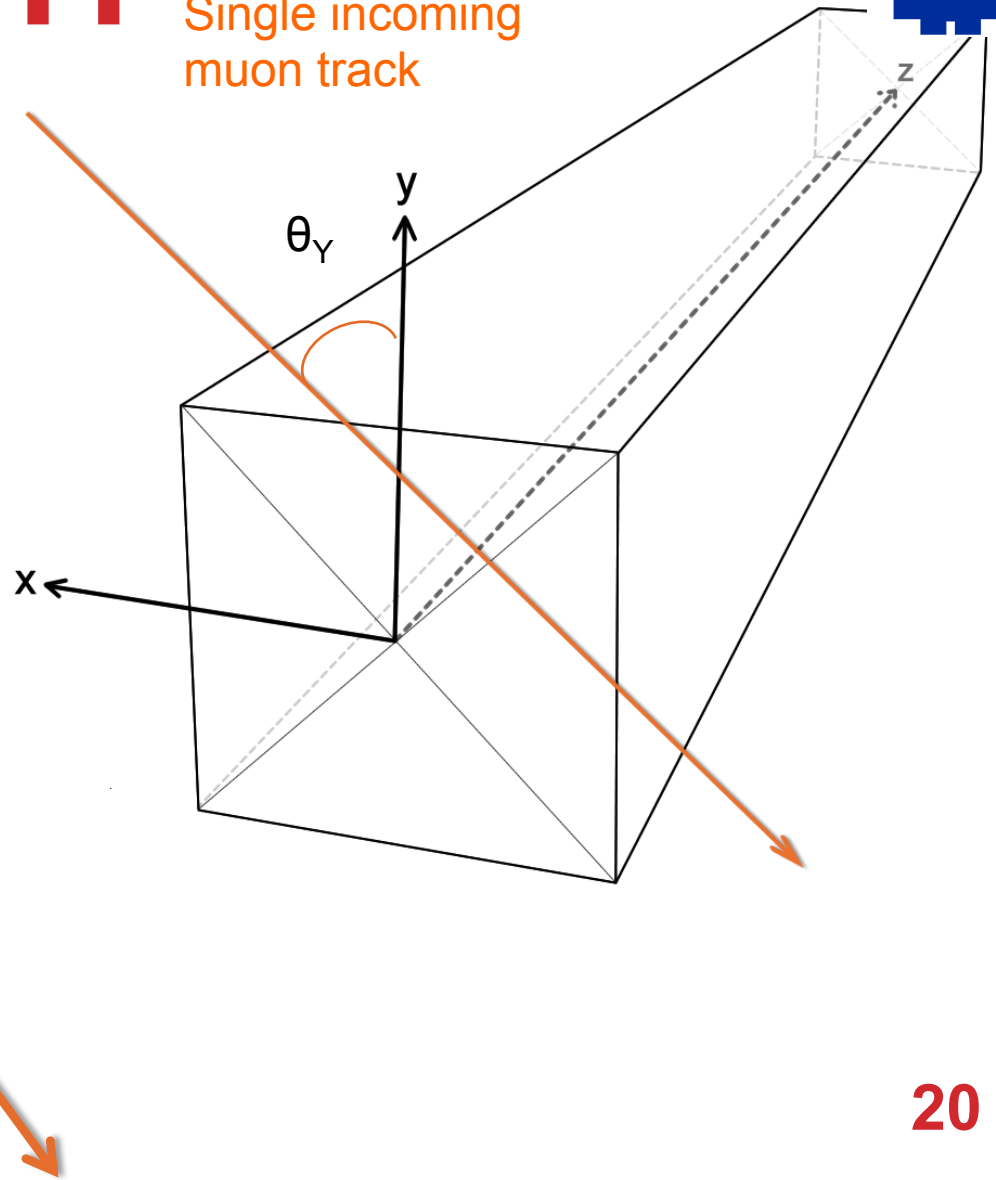


Aug. 4th, 2014

DIRECTIONALITY



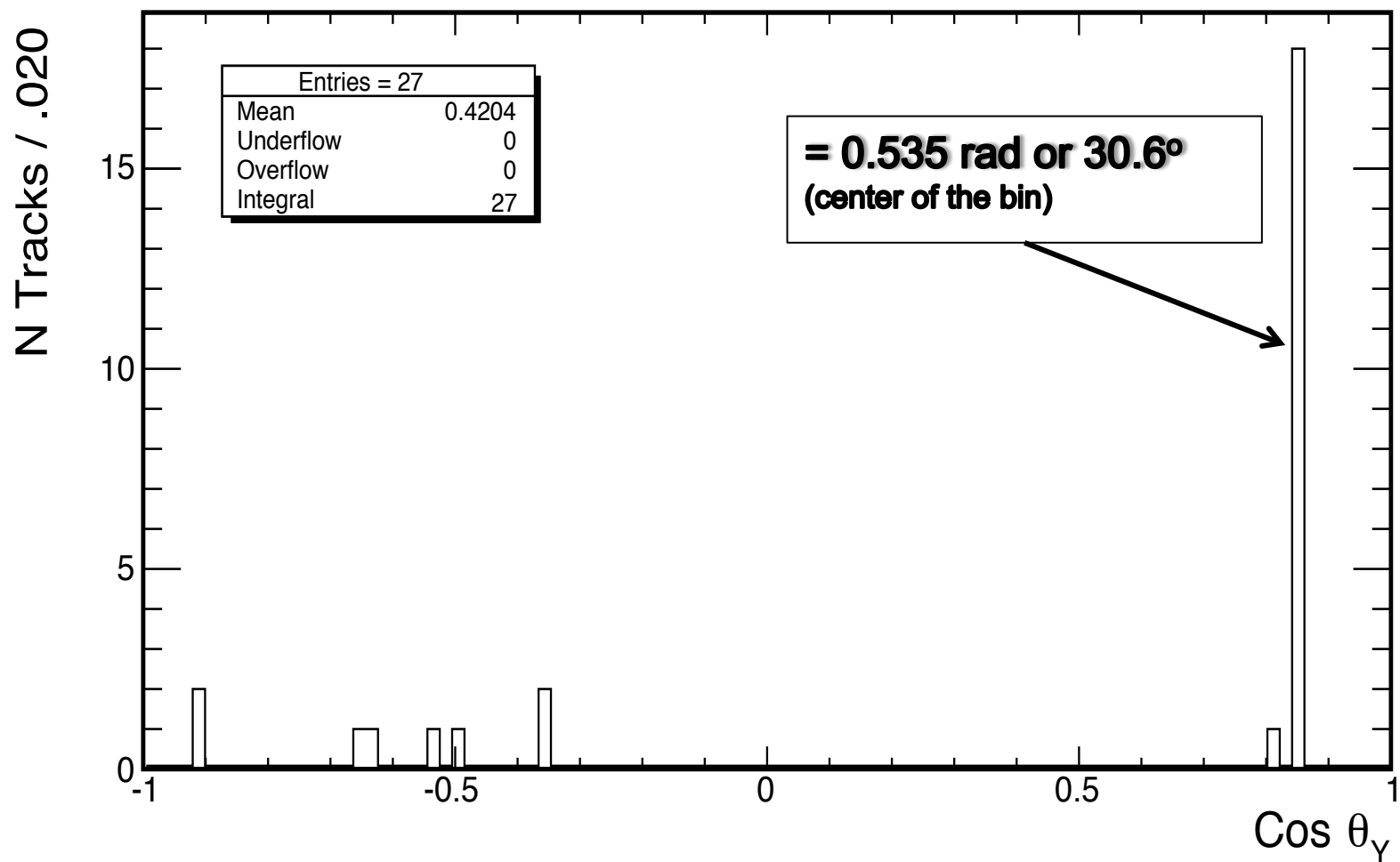
Single incoming
muon track

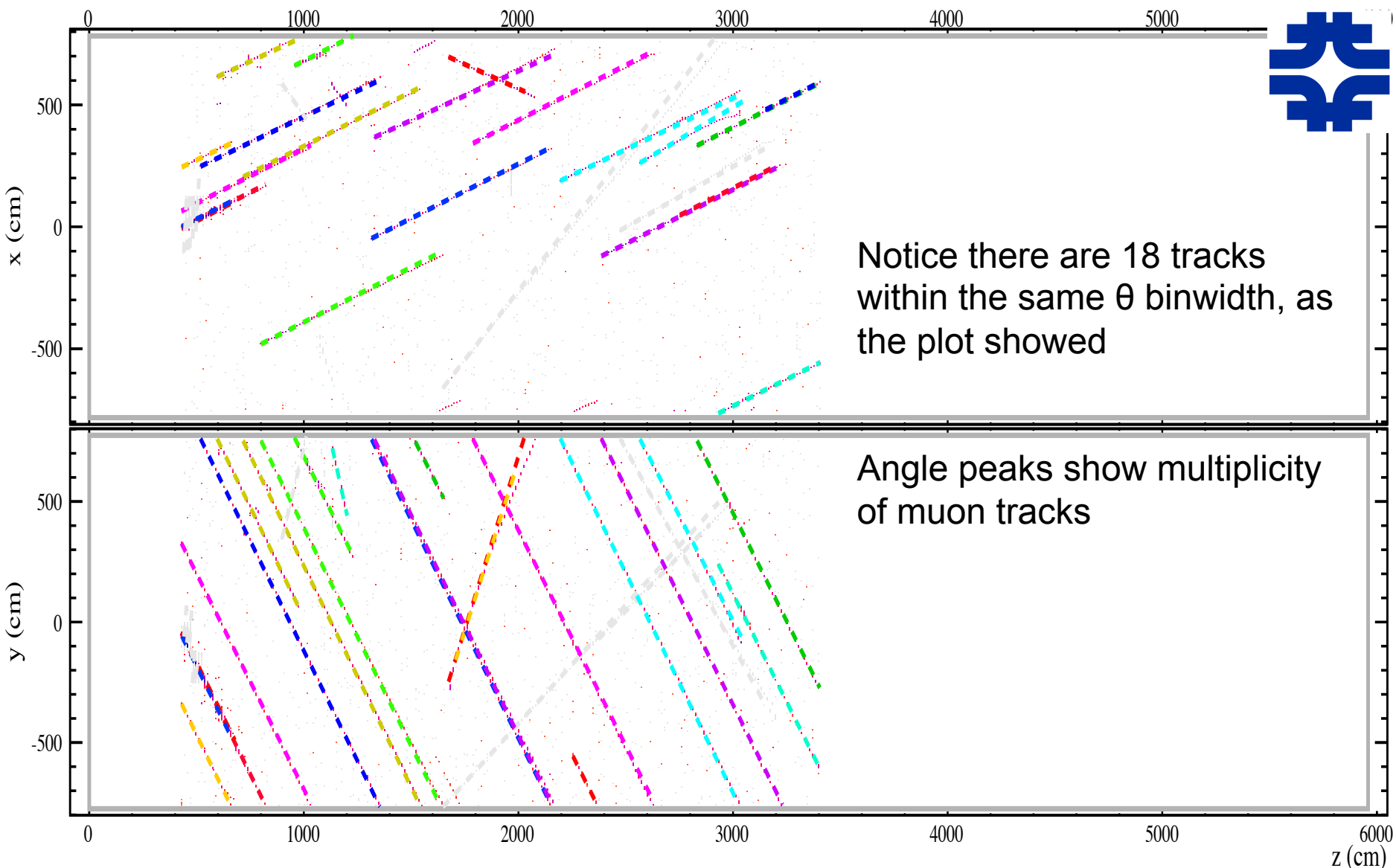
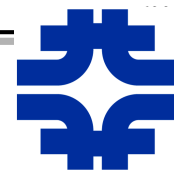


Single incoming
muon track



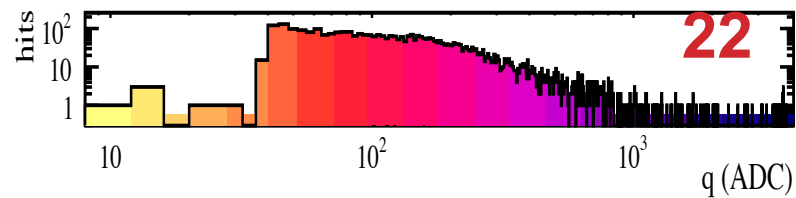
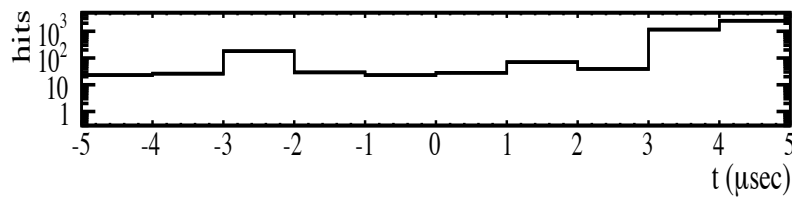
Angle of Tracks in Event 1727





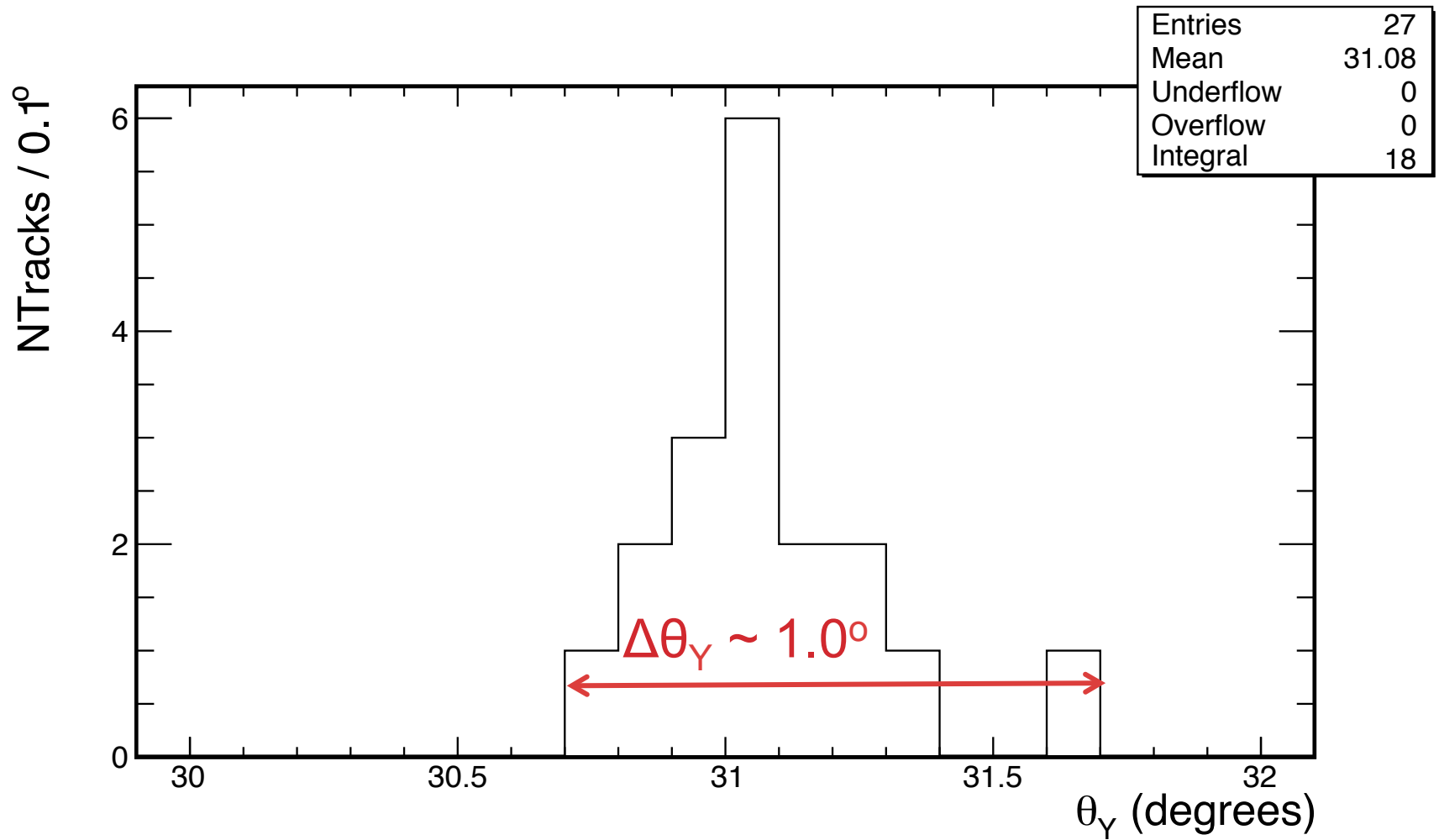
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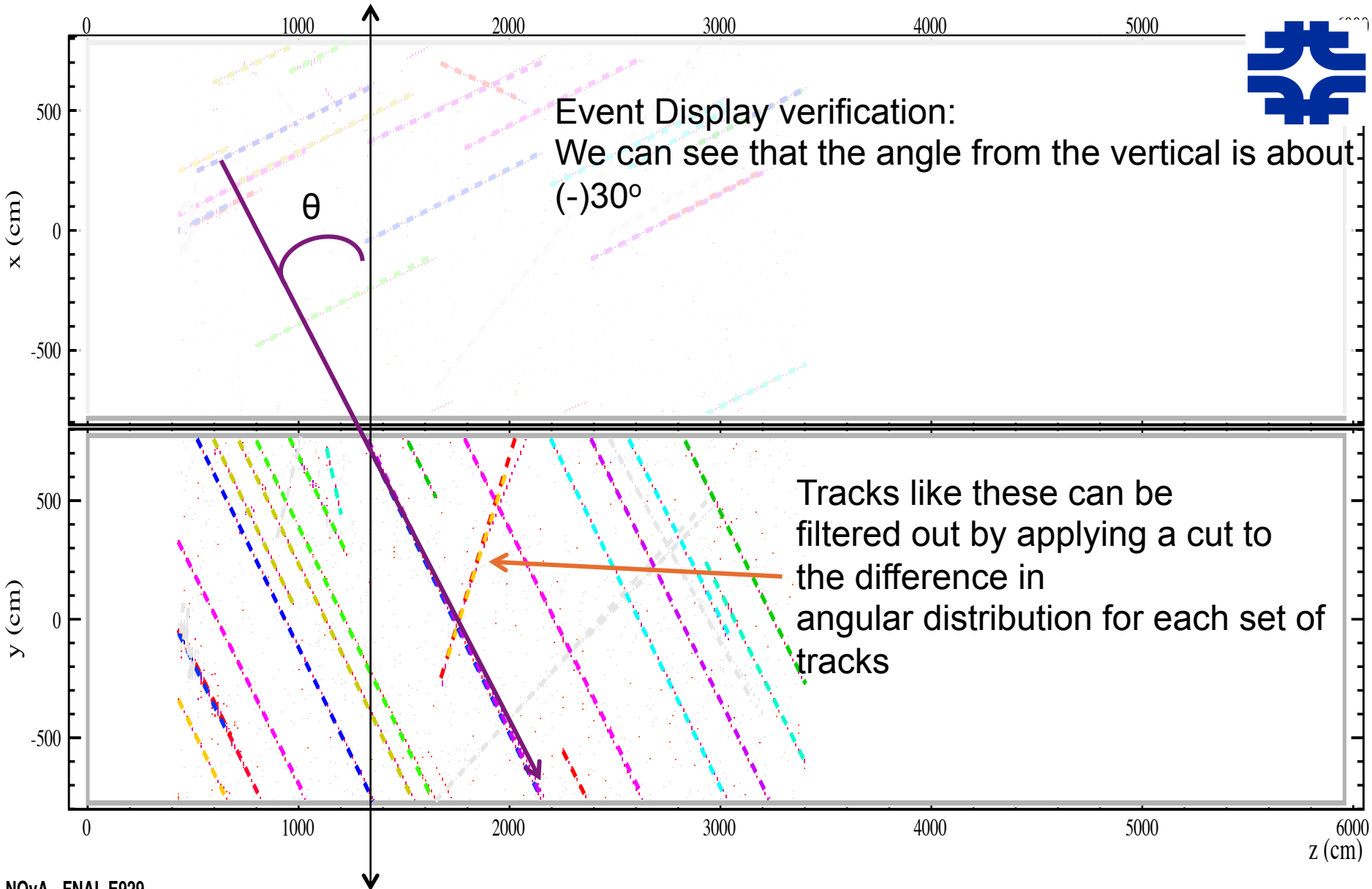
Run: 14870 / 0
Event: 1727 / DDenergy
UTC Fri Apr 25, 2014
03:12:22.582797504





Angle of Tracks in Event 1727 (Rebinned)

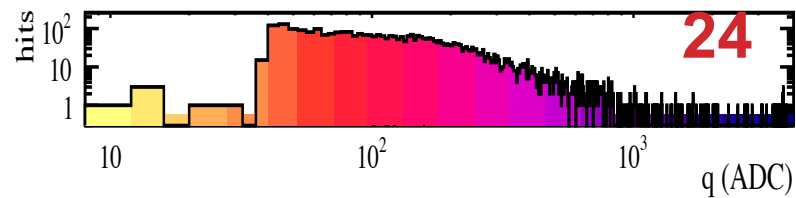
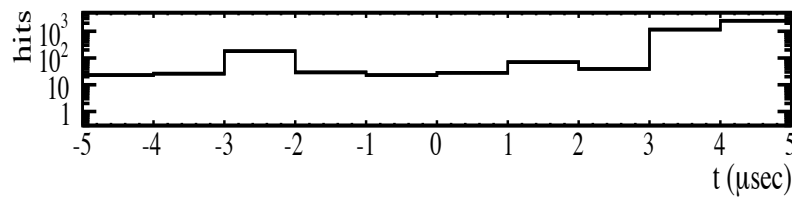




NOvA - FNAL E929

Run: 14870 / 0
Event: 1727 / DDenergy

UTC Fri Apr 25, 2014
03:12:22.582797504





NEXT STEPS & END NOTES

Hough Transforms works well in a reasonable time for large number of tracks in a slice in an event .

Kalman Tracking took 50 minutes(!) to plot out only a portion of the tracks in an event with a large number of hits. (shown later)

Need to see if these two options could be merged

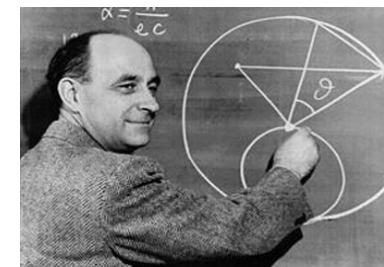
Need to run simulations and reconstruct the particle composition and angular momentum of the showers.

Future experimental prospects for this study could be to place smaller surface detectors around the Far Detector to get a sense of the timing, spread, and the multiplicity of the showers as a function of θ .

ACKNOWLEDGEMENTS



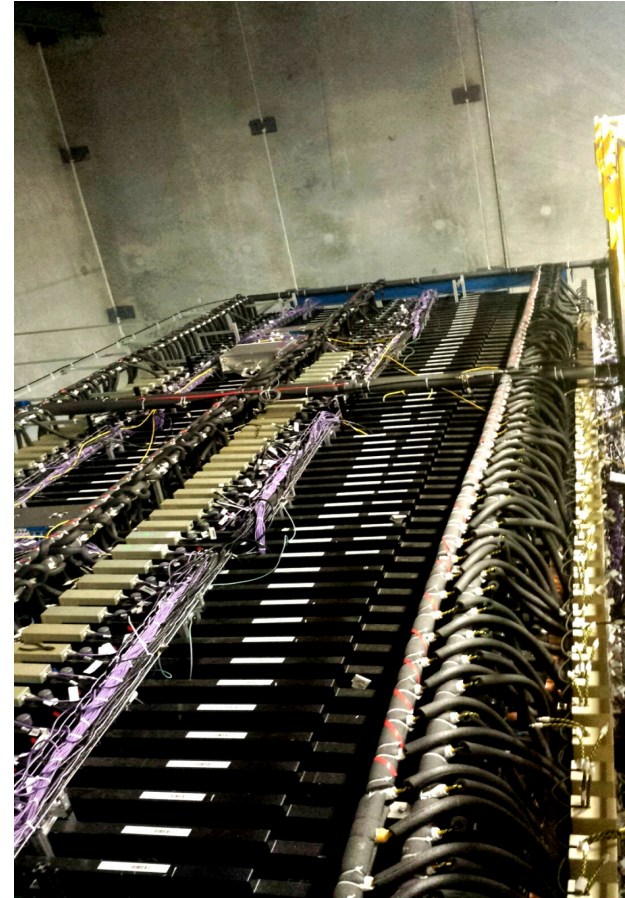
**SIST Committee
Mentors:
Dave Peterson
Mayling Wong-Squires**



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EXTRAS/ BACKUP



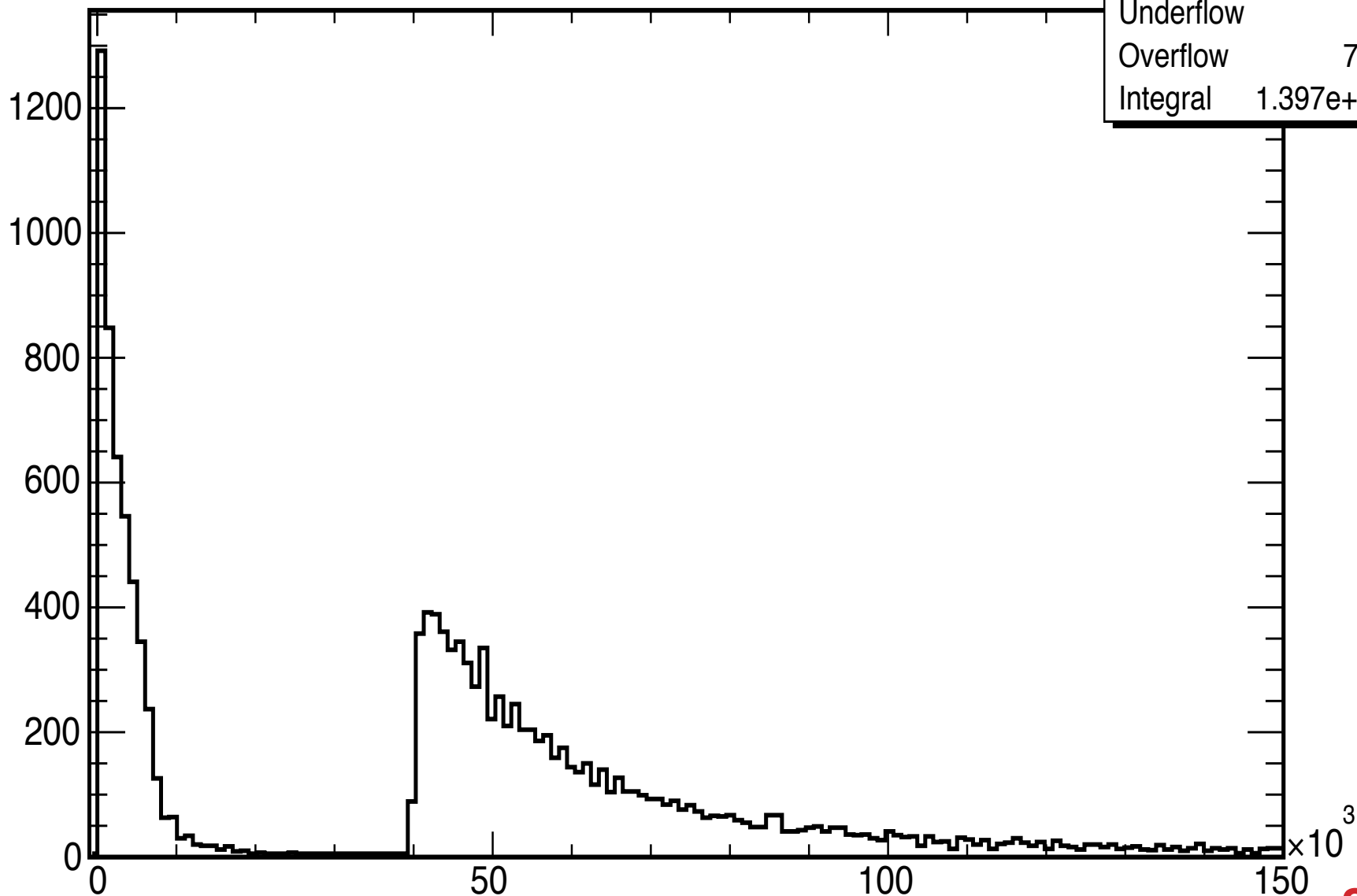
Notice the number of FEBs (Front End Board, the gold colored boxes) on each detector.

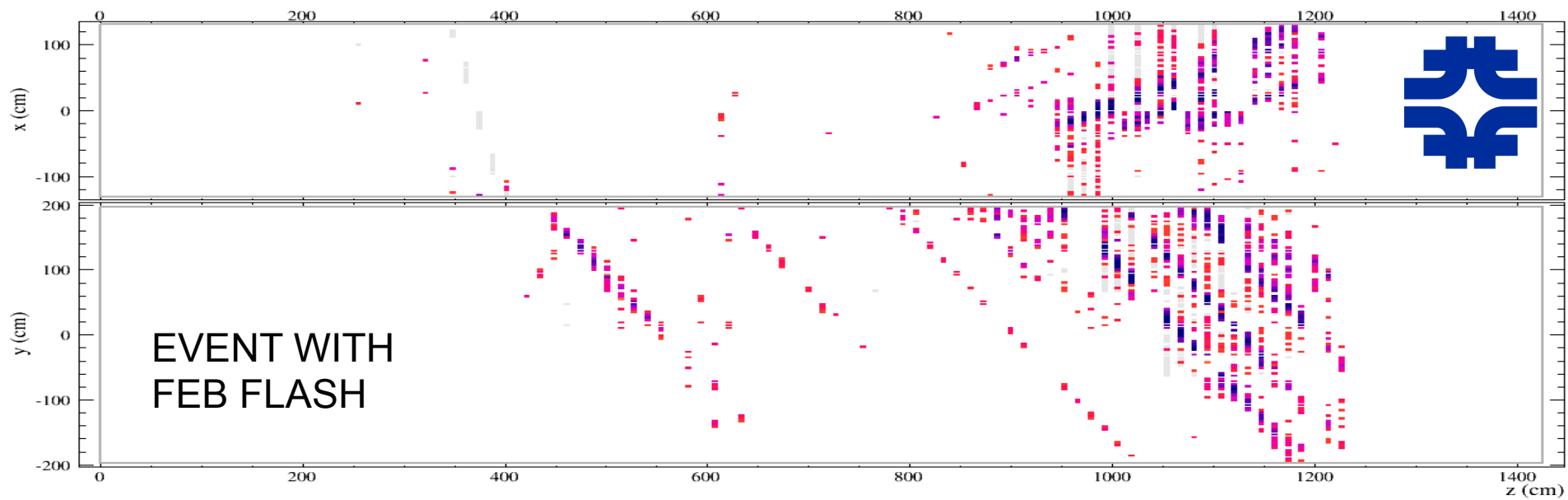
Data sets are significantly larger in Far Detector. But you can also see more particles in Far Detector

Total ADC Per Slice

Entries	14740
Mean	4.316e+04
Underflow	0
Overflow	773
Integral	1.397e+04

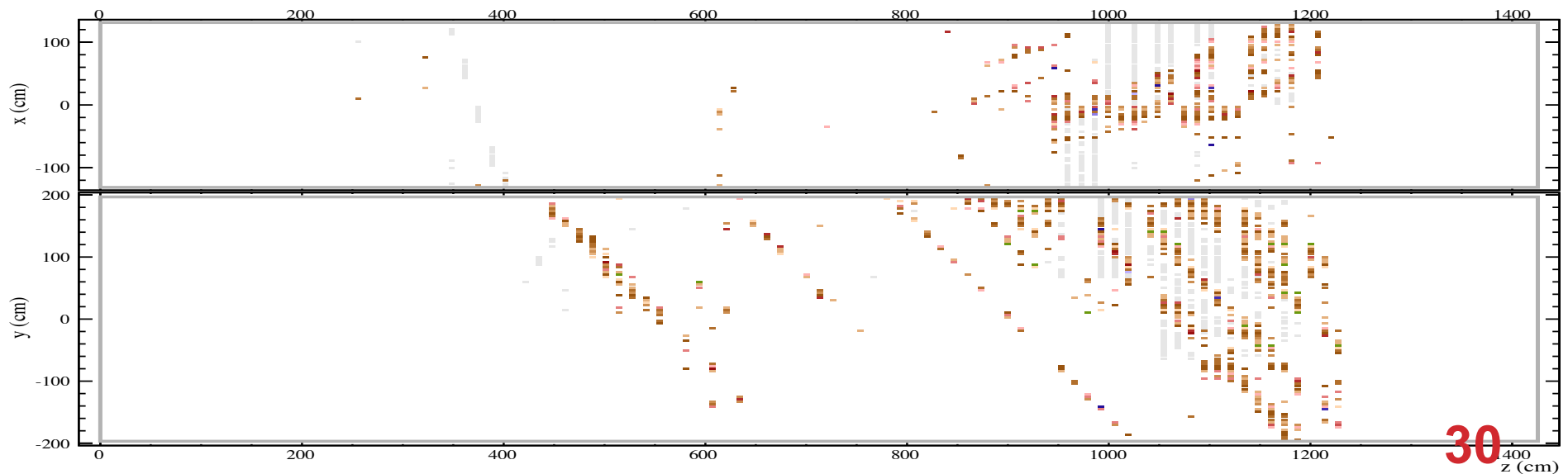
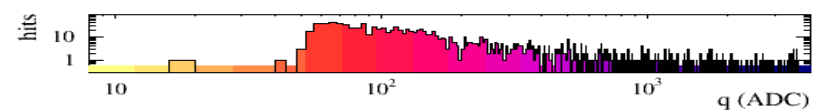
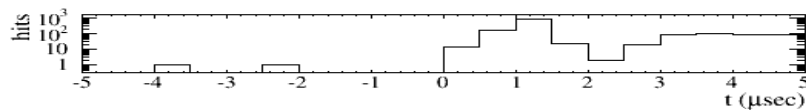
Number of Hits (bin width = 1000)





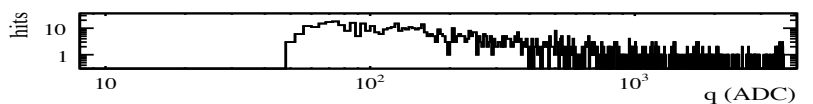
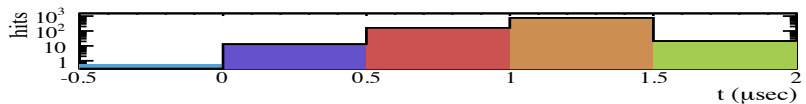
NOvA - FNAL E929

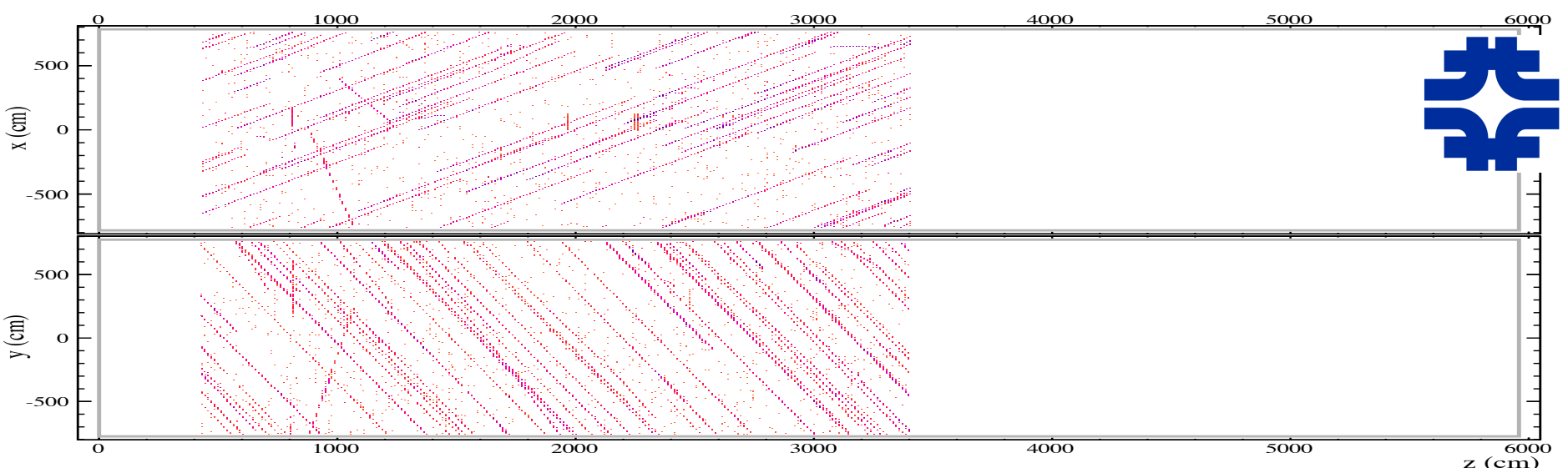
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Event: 4348 / DDenergy
UTC Fri May 9, 2014
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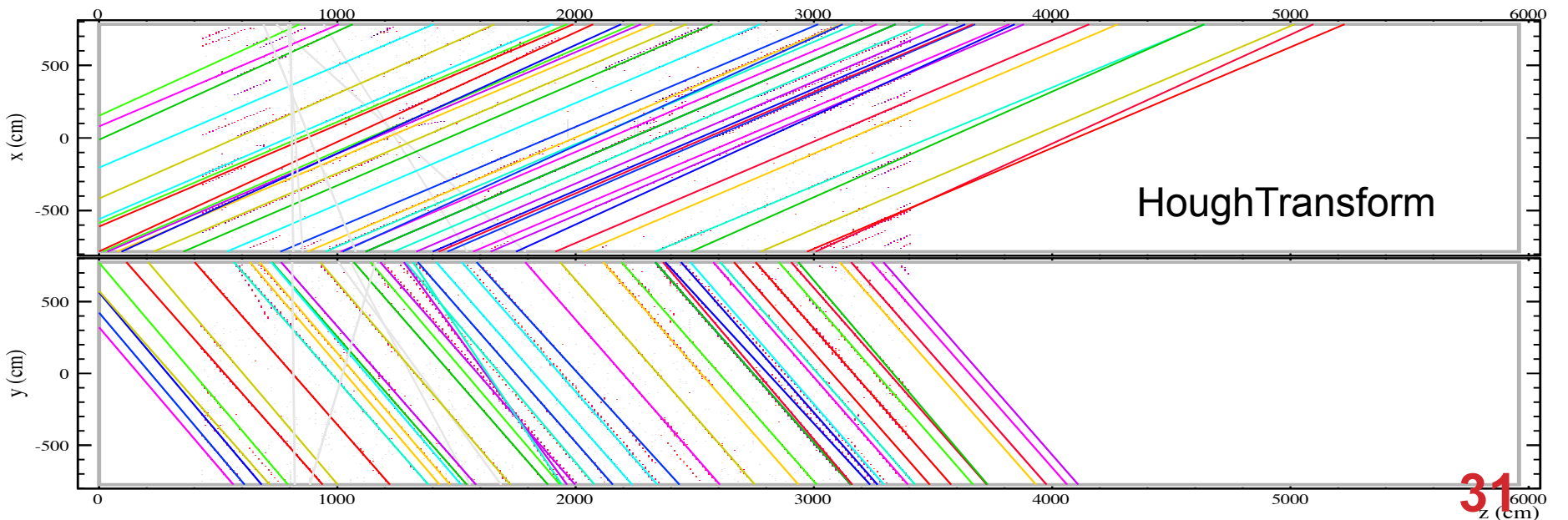
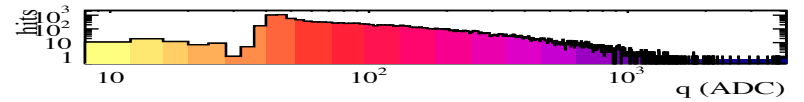
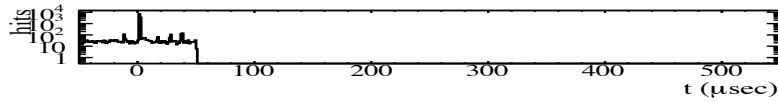
NOvA - FNAL E929

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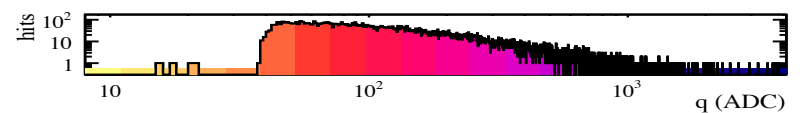
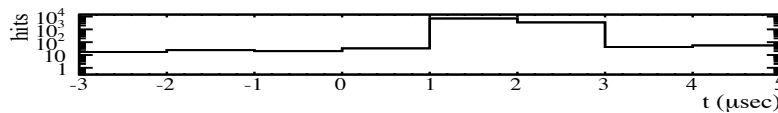


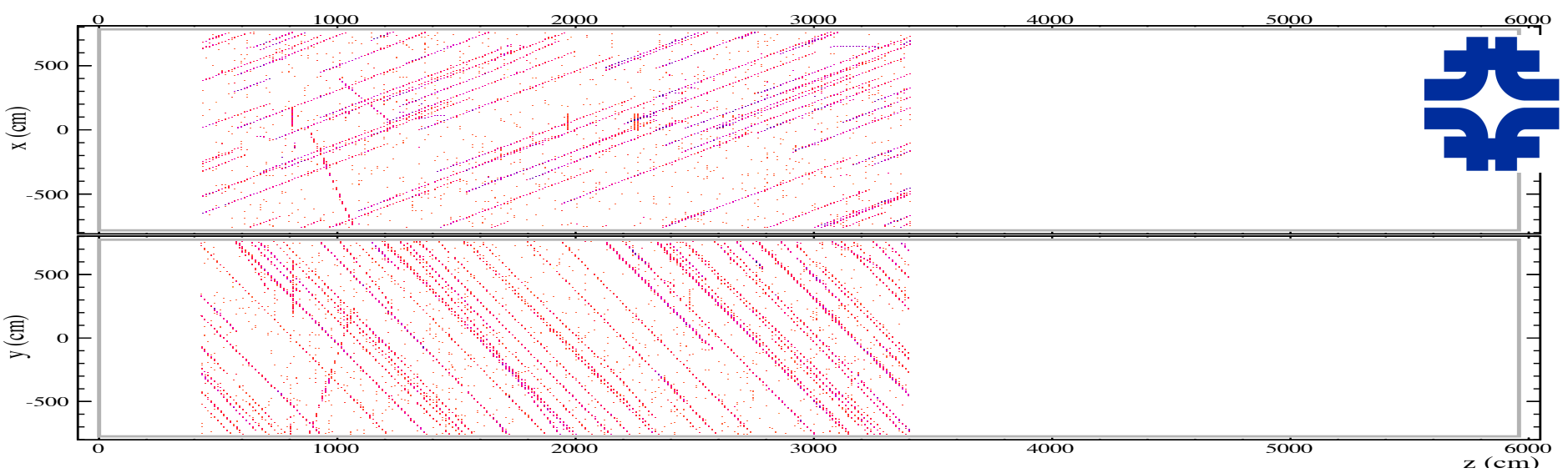


NOVA - FNAL E929
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 UTC Fri Apr 25, 2014
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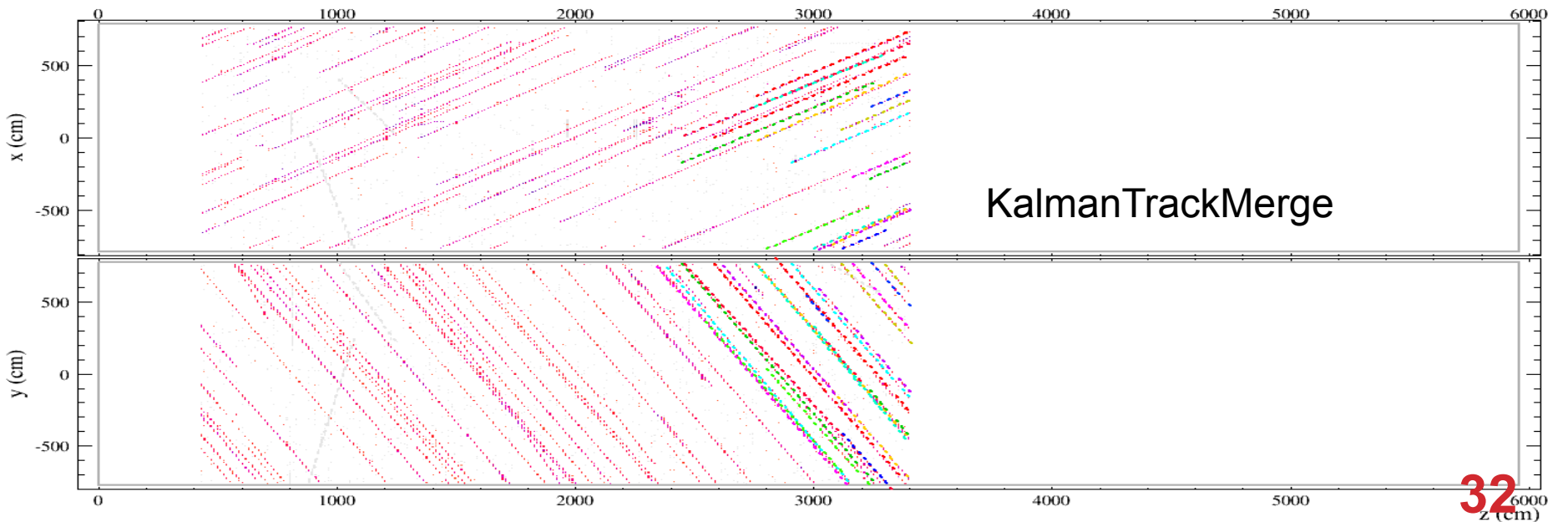
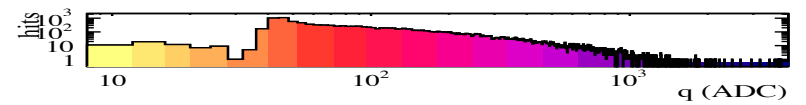
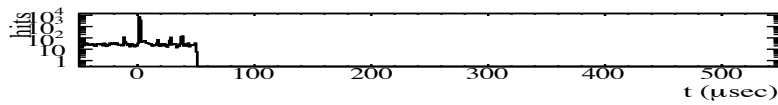


NOVA - FNAL E929
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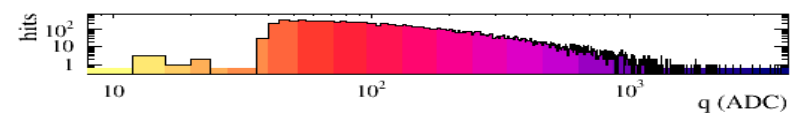
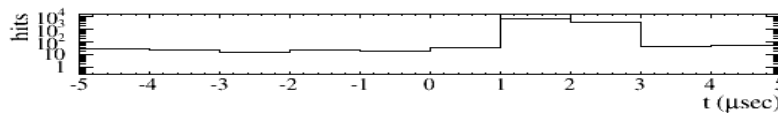


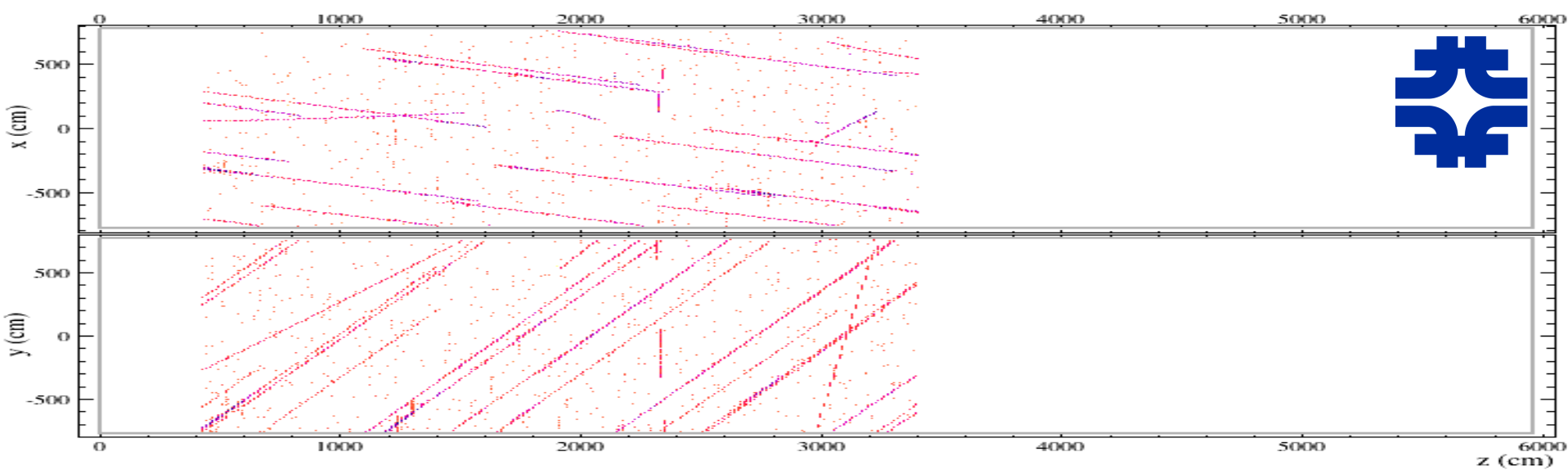


NOVA - FNAL E929
Run: 14870 / 0
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NOVA - FNAL E929
Run: 14870 / 0
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UTC Fri Apr 25, 2014
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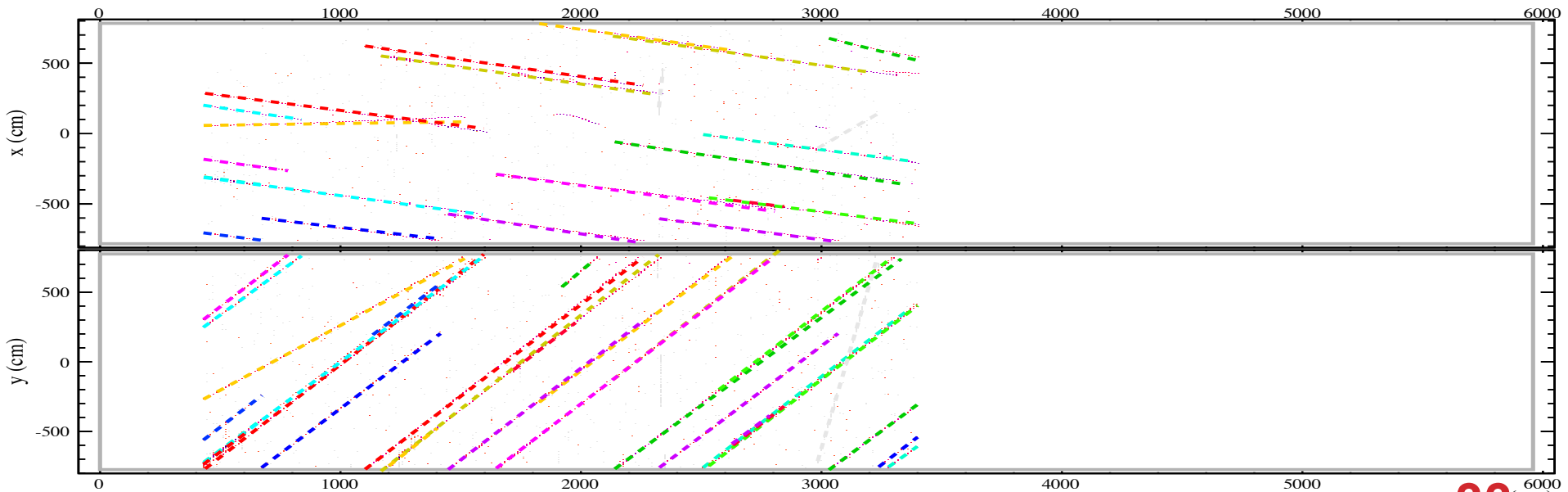
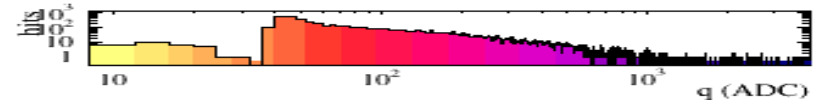
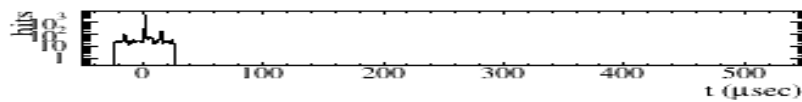
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Event: 1830 / DDenergy

UTC Fri Apr 25, 2014

03:12:21.644923520



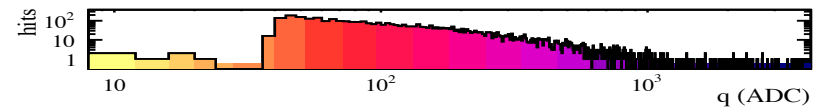
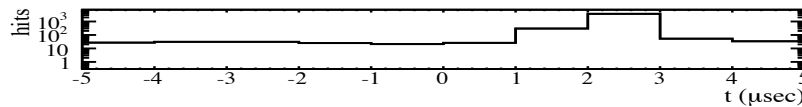
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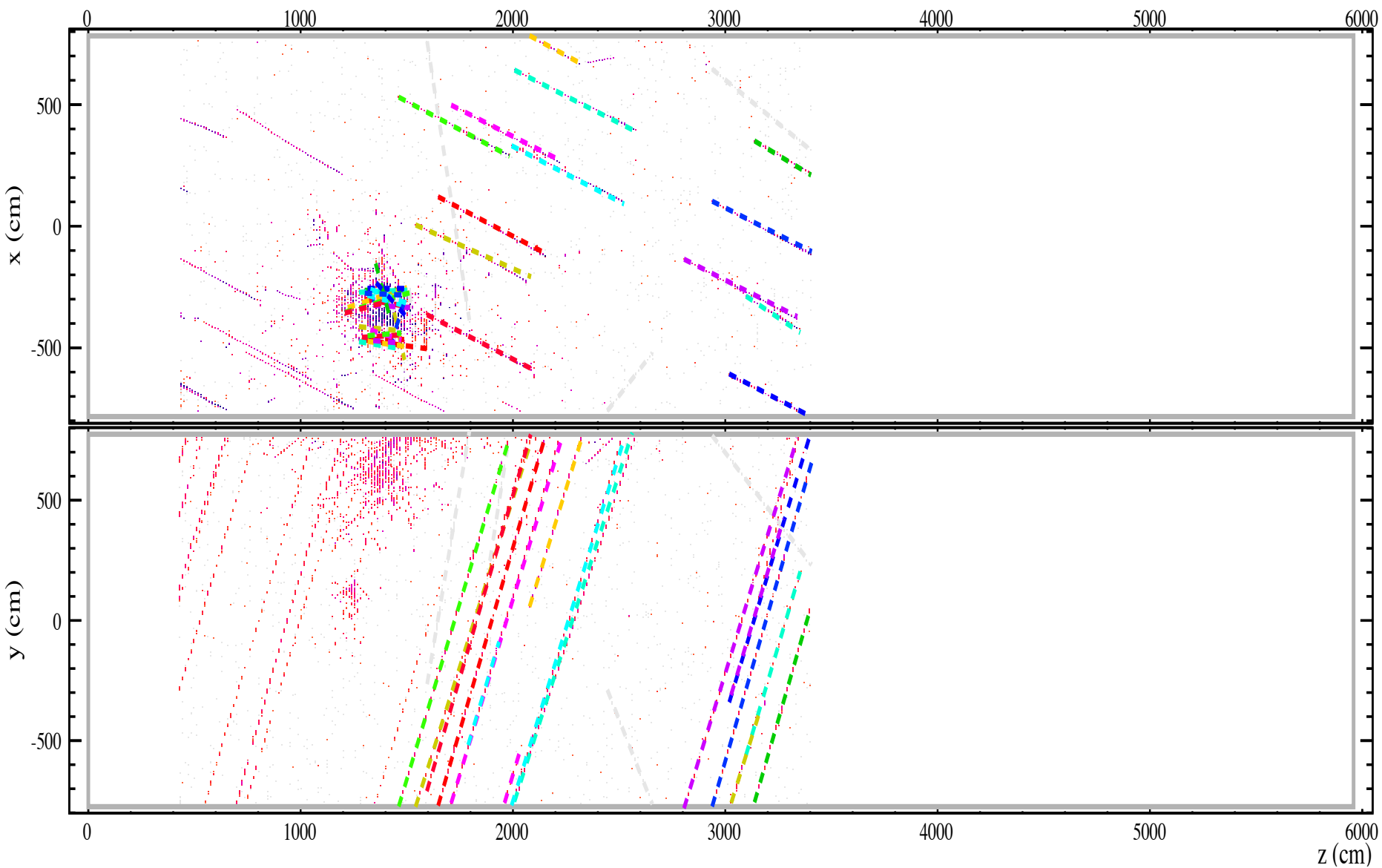
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UTC Fri Apr 25, 2014

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NOvA - FNAL E929

Run: 14870 / 0

Event: 268 / DDenergy

UTC Fri Apr 25, 2014

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